Low Profile, Single Feed, Tri-filar, Linear- or Circularly- Polarized Helix Antenna

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ABSTRACT

We have designed and built a small, low-profile tri-filar helix antenna, which can have either linear or CP polarization, with a single feed and no internal feed network. This antenna is comprised of three bent quarter wave monopoles (an element), positioned at 0, 120, and 240 degrees, respectively. One of the bent monopoles is fed, and the other two are parasitically coupled. Perturbations on the parasitic elements determine whether the antenna is linear or CP, and control the phases. To induce linear polarization, no perturbations are used and both parasitic elements are coupled at +120 degrees. To induce CP polarization, the resonant frequency of one or both of the parasitic elements is slightly shifted using perturbations. As a result, one of the parasitic elements couples at positive 120 degrees to the directly fed element, and the other at negative 120 degrees. Various perturbation options are available to generate this phasing: slightly increase or decrease the length of a parasitic element or elements; one of the arms can have a capacitive shunt; the other parasitic element can have a series inductance. Only one arm needs any perturbation, either capacitive or inductive, depending on the sense of the CP desired. The elements can be supported using a dielectric substrate, or can be free standing. A ground plane is necessary only directly under the elements. This antenna can replace a dielectrically-loaded single feed linear or CP patch, and does not require the dielectric loading. Hence this design is a less expensive choice for narrow band antenna applications.

BACKGROUND

Low profile, small circularly polarized antennas are used in the mobile communication industry, usually for satellite communication. As the demand for mobile handsets increases, there is a growing need for these antennas, especially for low cost GPS antennas. Currently the standard industry solution for low profile CP antennas is to use a patch (microstrip antenna). In order to achieve CP, these patches need to be a half wavelength long. The free-space half wavelength is usually too long for the compact space in a mobile handset, and the antenna size needs to be reduced dramatically using high dielectric ceramics. The use of these high dielectric ceramics increases cost, and adds the potential for lossy materials and reduced effficiency.

The market for low profile, compact CP antennas is one of many markets for CP antennas. For applications that provide space for larger antennas, the following additional CP antennas are standard solutions: 1) Single Helix, typically a few wavelengths tall. 2) Multi-filar Helix, typically a few wavelengths tall. 3) Crossed Dipoles, a quarter wave over a ground plane. 4) Spiral antenna, a quarter wave over a ground plane.

Tri-filar ANTENNA

This tri-filar antenna was developed using a standard commercial FEM software, Ansoft HFSS. The software models realistic antennas, including dielectrics, 3D structures, and finite ground planes. Also, an arbitrary number of ports, with user-defined power and phase, can be used so that the antenna can be designed without the need to design a feed network.

The new antenna is a small, low-profile tri-filar helix antenna, which can have either linear or CP polarization. Before describing the subtle adjustments necessary to create the final antenna, it is useful to consider the precursor geometry that forms the basis for this style of antenna, shown in figure 1a. This precursor geometry is comprised of three bent quarter wave monopoles (1,3,5 in fig. 1a). The bent monopoles (an element) are positioned at 0, 120, and 240 degrees. The elements can be supported using a dielectric substrate(9), or can be free standing. A ground plane is necessary only directly under the elements. Precursor here means that the antenna is not yet converted to a single feed antenna, and it is not yet converted to linear or circular polarization. This conversion to a single feed will be accomplished later using the strong coupling between the elements to allow the second and third elements to be parasitically excited, even though only the first element is directly fed. The CP conversion will be accomplished using perturbations of the parasitic elements.

The behavior of this precursor geometry can be predicted by feeding each of the three elements with their own port. The existence of these three ports (11,13,15 in fig. 1a) allow computer simulation to predict the coupling between the elements, upon which the final design depends. The input match, shown in Figure 1b, is controlled by the inductive shunt (7) at the base of each element. Each element is a single bent monopole, and has a radiation resistance which is much lower than the typical 50 ohm signal sent to the antenna. Hence this matching structure or component is necessary. Energy needs to get past the feed point before it can ever couple to the other elements or even radiate, hence this matching structure is a crucial part of the design. The magnitude of the coupling, approximately 6 dB to each element, is also displayed in Figure 1b (half the power is coupled to the other elements). The coupling is to a large extent controlled by the width of the capacitive gap between the edges of the elements on the top surface.

In the final design, when only one element is directly fed, it is necessary to induce large coupling between the directly excited element and the parasitic elements for many reasons. One, this large coupling effectively acts as a feed network to the two coupled elements, and allows the antenna to have just one of the elements directly excited. Two, when all the elements have equal energy in the resonance condition, the antenna will generate symmetric radiation patterns. A good recipe for a design, in this precursor geometry, is to have half the energy coupling to the other elements and the other half radiating into free space. If the coupling is larger than this, then each element is a poor radiator and the efficiency of the antenna suffers. If the coupling is less than this, then it is difficult to parasitically excite the other elements and generate circular polarization.

With no perturbations on the parasitic elements, the phase of the coupling between the elements is +120 degrees, as displayed in Figure 1b. The values of the phase of the coupling are crucial in order to induce either linear or circular polarization. Perturbations on the parasitic elements offset the resonance frequency of the individual element and will affect the phase of the coupling.

Figure 2 displays the final linear antenna which exploits the strong coupling and uses only a single feed. In order to generate a linearly polarized antenna, only one of the elements in the precursor geometry needs to be fed, and the unperturbed +120 degree parasitic coupling to the other two elements generates the linear polarization. The directly excited element is fed with an inductive shunt match. The linear radiation pattern is "patch-like", following the Ludwig 3rd definition. The polarization is parallel to the axis through the feed point and center of the antenna.

To induce CP polarization, one of the parasitic elements needs to couple at positive 120 degrees, and the other at negative 120 degrees. This generates an electric field which rotates around the perimeter of the antenna uniformly with time. In practice, the basic goal is to slightly shift the resonance frequency of one or both (one up in frequency, one down) of the parasitic elements using perturbations. Various perturbation options are available. The most basic technique to shift the resonant frequency is to slightly increase or decrease the length of the parasitic element or elements. Other techniques to shift the resonance of the parasitic elements are also possible, as shown in the following. Figure 3 displays a final CP antenna with a single feed, using a capacitive perturbation. Note the parallel capacitive stub which extends inward at the base of the parasitic element, and lowers this element's resonant frequency. Figure 4 displays a final CP antenna with a single feed, using an inductive perturbation. One of the parasitic elements has a lower series inductance at its base, which raises this element's resonant frequency. Note the wider metal at the base of the parasitic element. Wider metal conductors, positioned where the current is a maximum, have less inductance than thinner metal conductors. Alternatively, both arms can have perturbations, one a capacitive stub and one a series inductance. Any small change in the shape of the element, either at its base or at its top, will create a perturbation and change the phase of the coupling. The sense of the CP can be reversed by switching the perturbation to the other parasitic arm.

Figure 5 displays the measured RH and LH CP radiation patterns, at the center frequency, for a built prototype antenna. The axial ratio is nearly perfect at 0 dB. The A.R. 3dB bandwidth is about 10 MHz at 1575MHz center frequency.

This antenna will have better efficiency, as is typical with most antennas, when the complete antenna is wider or taller. Better efficiency will be achieved using taller bent monopoles, under the constraint that the strong coupling between the elements must still be insured. This ideal of taller elements becomes impractical after a certain height because the directly fed element is so efficient in itself that it radiates most of its energy before the energy can be coupled to the parasitic elements. Spacing the elements farther away from each other will also increase the efficiency, but the same limitation regarding coupling applies. The elements must be close enough to each other that significant coupling occurs.

Note that this tri-filar antenna, using very little dielectric loading, is the same size as the highly dielectrically loaded patch antenna, er = 40. Hence this tri-filar antenna can replace a dielectrically-loaded single feed CP patch of the same size, and does not require the dielectric loading. This design is a less expensive choice for narrow band CP applications.

The above models assumed two shot molding manufacturing process to create the antenna, with only the top and sides plated. Other possible techniques are: 1) two shot mold, with the elements plated on both the top and the bottom, creating a non-dielectrically loaded antenna, 2) insert mold, 3) a hybrid antenna using an etched PCB and stamped metal design, and 4) a completely PCB design.

Applications can be GPS antennas on handsets, and wireless LAN's (2.4 & 5 GHZ). There has been a lot of empirical testing that suggests that CP works well for the access point. Certainly the ability to have a linear AND a CP source would work well for diversity applications. The antenna would essentially be the same except for, possibly, a pin diode controlling the perturbation, and it would be low cost which is obviously important.

Conclusion:

From computer modeling to lab measurements, we have designed and built a novel small, low-profile Linear or CP tri-filar helix antenna, comprised of three bent monopoles and a single feed point. CP is achieved using a perturbation on one or both of the parasitic elements.

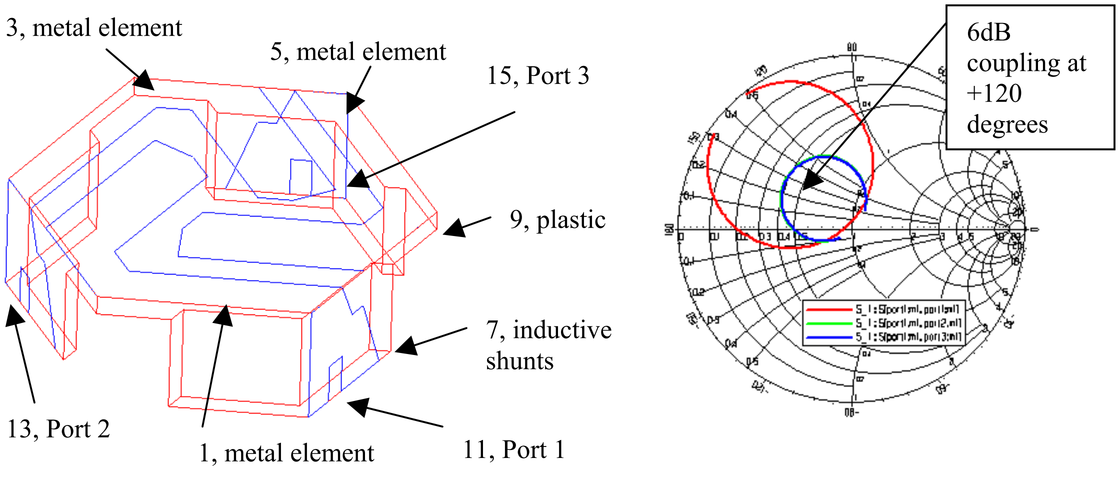

Figure 1A,B: A: Tri-filar "precursor" antenna with no perturbation on the three identical elements, and three ports. The vertex to vertex distance is 0.88 inches, and the flat to flat distance is 0.72 inches. B: Magnitude and phase of the coupling between the directly excited element and the parasitic elements, of approximately 6 dB and +120 degrees at the center resonance of 1.575 GHz.

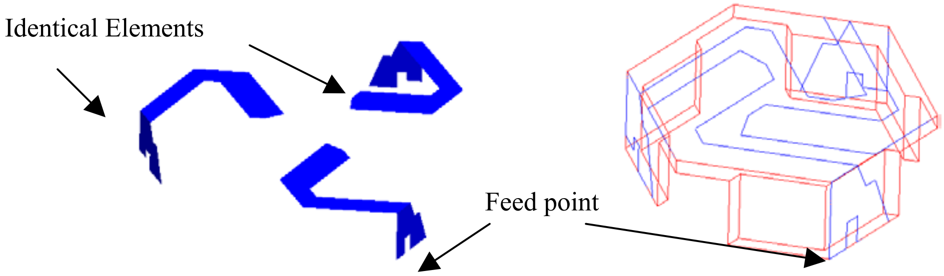

Figure 2: Linear polarization, Exploded elements and final dielectrically-supported linear antenna, with no perturbation on parasitic elements. A linear polarized “patch-like” radiation pattern is produced.

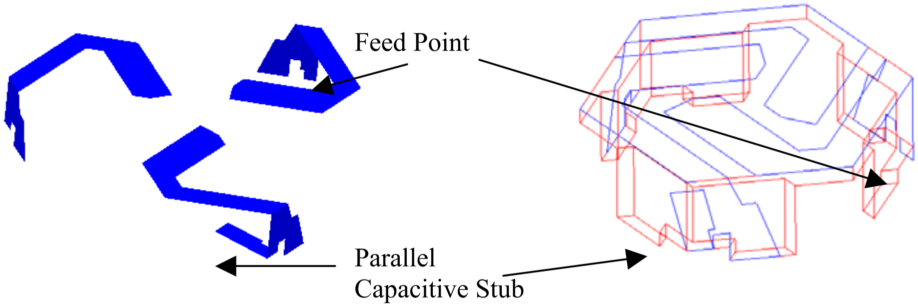

Figure 3: Circular polarization, Exploded antenna elements and final dielectrically-supported CP antenna with incorporated capacitive-shunt perturbation on one parasitic element, using a single feed.

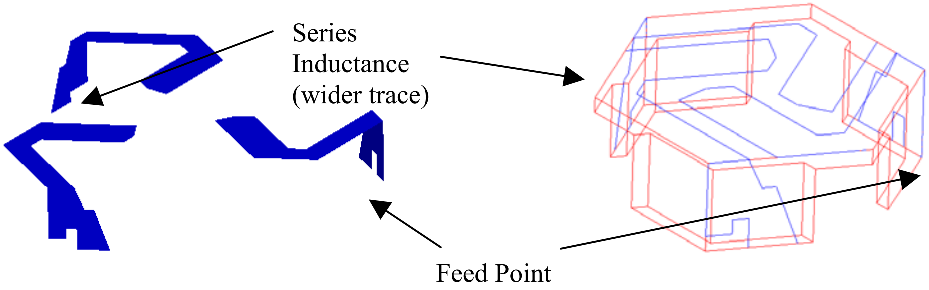

Figure 4: Circular polarization, Exploded antenna elements and final dielectrically-supported CP antenna with incorporated series inductance perturbation at the base on one parasitic element, using a single feed. RHCP radiation is produced.

Figure 5: Measured GPS tri-filar antenna, LH and RH CP polarization.